TARGET LOCALIZATION, IMPROVING TRACKING ACCURACY AND ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORK

Abstract:

Invention of small form factor processors with large computing power has given rise to development of relatively less expensive sensor nodes. This is fueled by demand of processors for automation in every course of life. Thus, chip production in large volume has reduced cost of sensor nodes. They are equipped with processor, sensors and RF radio and employed for number of important applications. Target tracking is very important component for surveillance application, specifically for detecting vehicle or it's maneuvering and it also demands secrecy. Wireless sensor network (WSN), formed by tiny sensor nodes serves this purpose well, along with localizing targets.

Wireless sensor network has limited energy source on sensor nodes. Thus, energy is scarce resource. In most cases nodes are non-recoverable and non-maintainable after their deployment. But, wireless sensor network is built to last for longer and provide service adequately during their life time. So, energy efficiency in WSN and target tracking is very important and so focus of this work. Target tracking using wireless sensor network is analogous to localizing object by a blind person, who cannot see it but can estimate distance to the target through ears and finally locate the object. In case of WSN, such job of distance measurement is accomplished by the sensor nodes, and combination of these measurements is utilized to localize the target.

Energy efficient target tracking techniques is implemented either at node level, protocol level or even at application level. Exploiting inherent nature of the target tracking, one can build efficient techniques. Each distributed sensor node measures distance from the target, at progressive instants of time. Such series of measurements are transferred to intermediate nodes, then to cluster head, and finally to sink node through proper routing protocol. Target location is computed at cluster head level. It also estimates future positions of target, using prediction filters. These predicted values are utilized to activate other sensor nodes, which normally remains in the sleep mode.

Proposed thesis improves target detection accuracy, which is quantified in terms of root mean square (RMS) error. Variations in: a) cluster size b) distance measurement accuracy of the sensors c) density of distributed nodes is considered during target detection. Energy dissipation in network, for these variations is computed and compared. It should be noted that, although accuracy of target tracking is achieved by prediction algorithms, like Kalman filter (KF) , extended Kalman filter (EKF), particle filter (PF) and its variants, it does not contribute significantly towards energy conservation in the WSN.

It is concluded in the current work that increasing cluster size improves target tracking accuracy in WSN but, increases energy consumption. This is due to demand of increase in measurement range for all sensor nodes which will fetch more valid number of sensor node measurements at cluster level. Energy efficient mechanism is employed by reducing number of nodes, developing reporting mechanism to cluster heads for their measurement outcomes. This reduces communication cost and hence overall energy consumption in network is minimized.

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Synopsis

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1.1 Wireless Sensor Networks, an introduction

Wireless sensor network (WSN) is defined as the network consisting of large number of tiny sensor module, deployed with relatively high density in the finite area of interest for surveillance or monitoring application. Such sensor modules are called sensor nodes. Deployment mechanism is less complex and cost of such network is lower than the traditional wired sensor system. Purpose of employing large number of sensor nodes, is to get accurate and reliable measurements. Key attributes of such networks are 1) nodes are unattended 2) limited energy 3) topology is unknown. Design of the wireless sensor network, is more challenging due to their limited resources. Many times they are deployed in hostile environments [1].

In most cases, sensor nodes are likely to be stationary for their entire lifetime compared to the mobile adhoc networks. The topology of the network can change due to failure of the nodes or other reasons, but sensor nodes locations remained fixed. Since the sensor nodes have processor, intelligence can be developed and data can be processed as message propagates through the network. The message propagates wirelessly using networking protocols.

Sensor nodes are equipped with memory, sensors, wireless radios, and processor. Recent advancement in electronics and miniaturization has made it possible to produce inexpensive sensor nodes. Such sensor nodes are capable to monitor variety of ambient conditions like temperature, pressure, humidity, soil makeup, vehicular movement, noise levels, lighting conditions, presence or absence of certain kinds of objects, mechanical stress levels on attached objects and many more. Integration of emerging low-level and low-power wireless communication protocols with such sensor nodes helps to network them for longer duration. Such equipped sensor nodes adds new dimension to their capabilities. They are capable of coordinating amongst themselves a higher-level of sensing tasks like reporting phenomenon which can be accomplished with greater accuracy. Network finds accurate estimates of speed, direction, size, and other characteristics of the approaching vehicles.

Typical attributes to be considered for wireless sensor network are sensor type, how sensor nodes deployed, their power consumption, operating environment, computational power, sensing and communication capabilities, signal processing etc.

1.2 WSN Applications

The application of wireless sensor networks include: military, medical, environment monitoring, target surveillance, health control etc. Military applications comprises of detecting and monitoring enemy vehicles or objects in the war field or monitoring their own objects that are distributed randomly in a remote area. Environmental applications are useful for detecting and observing environmental changes or weather forecast, where it may not be possible for humans to physically stay and observe, habitat monitoring etc. In the medical field, small, wireless sensor chips attached to a patient detect the changes or reactions that happen to the body and convey this information to a processing unit.

2.1 Target Tracking Problem

WSN can be typically used to monitor the environment, and it could be employed for the location tracking problem. Primary goal of tracking is to trace the path of moving objects or individuals in the sensor deployed area, called sensor field. This problem is more challenging due to many constraints at sensor node level, like there are no centralized control mechanisms or backbone network, nodes does not have unlimited energy resource, sensors may not have great accuracy.

One can understand problem of target tracking with analogy to policing in the desert area, where by, deputed soldier does not have unlimited resources, has limited capabilities and equipments and one has to survive for long time using available scarce resources optimally. He has to interact with other deputed personnel and transfer information further. Soldier has to intersect intruder passing through in the nearby region, he has to remain alert and continue to look in the periphery of his check post. When such soldier is blind, then job becomes even more difficult, which is analogous to situation of sensor node having acoustic sensors only. Soldier has to report such intruder, track path by continuously watching intruder based on the measurements carried out.

One well-known method for location tracking is, using global positioning system (GPS). However, GPS has its limitations. It depends on orbital satellites; it cannot be used in indoor environments very accurately due to dependency on line of sight (LoS). Even in non-urban outdoor settings, GPS does not yield accurate localization of target because it depends on many factors such as terrain, foliage and topographical settings of the place where the object is located. GPS receivers have size constraints, and it is power intensive for continuous operation. Most important is that object to be located must be equipped with such receivers which may not be true for several applications like surveillance and target tracking of enemy vehicle, which does not have friendly communication with networked data collector.

Wireless sensor network provides us better alternative for location tracking since the nodes are relatively small, inexpensive and they are low power devices. They are much more viable considering economic and convenience constraints. Target tracking can be used in air traffic control, fleet tracking, habitat monitoring, mobile telephony, vehicle tracking etc. The sensors need to detect the presence of an object in its sensing area, predict its movement and alert the sensors which are close to the predicted path of the target. Efficient use of node energy is one of the most important factors in target tracking because the sensor nodes are battery powered and it may not be possible to recharge the battery frequently, especially if the sensors are deployed in areas such as battle fields, forest, area with difficult terrain etc.

An emerging application area for smart sensor networks is intelligent surveillance or monitoring. Sensors are distributed, may be randomly in a geographic area to be monitored. The goal is to track and predict the movement of an target and alert the sensors which are close to the predicted path of the target. The target can be a moving vehicle or can be a phenomenon such as an approaching fire. It is assumed that each individual sensor node is equipped with appropriate sensory devices, able to detect the target as well as to estimate its distance based on the sensed data. The sensor nodes are triggered by the target, being in close proximity of target or phenomenon, also collaborate with other sensor node nearby and information about the target is shared. In few cases such alert if required serve as a trigger for these nodes to activate additional on-board sensors. For example, these additional sensors have different modality (e.g., alerts coming from heat sensors activating vibration sensors) that are ordinarily turned off or not sampled to conserve power. The alert can also serve as a trigger to actuate on-board devices depending on the capability of the nodes and the application.

It is expected to solve problem of designing an efficient tracking method based on WSNs that has the ability to cover large regions of interest by using many sensors with small detection range.

2.2 Challenges in Target Tracking

Design of a large magnitude tracking system with sensors gives rise to a number of challenges due to constraints associated with scenarios with sensor networks, specifically with sensor nodes.
1) Limited power available with sensor node due to the small size. 2) Large number of sensor node requires proper mechanism of deployment and coordination 3) Sensing signal with adequate signal to noise ratio (SNR) by individual sensor 4) Handle time synchronization and time stamping of sensor data which reveals target positions. Each of these issues needs to be addressed by any proposed algorithm in order to solve problem realistically and practically.

Few important attributes of target tracking systems using WSNs are as follows.

Tracking accuracy
To be effective, the tracking system should be accurate and the likelihood of missing a target should be low. Additionally, the dynamic range of the system should be high while keeping the response latency, sensitivity to external noise and false alarms low. The overall architecture should be robust against node failures.
Ad Hoc deployability
A powerful paradigm associated with sensor networks is their ability to be deployed in an ad hoc manner. Sensor nodes may be thrown in an area affected by a natural or man-made disaster or air dropped to cover a geographical region. These sensor nodes should be capable of organizing themselves into a network and achieving the desired objective in the absence of any human intervention or fixed patterns in the deployment.
Computation and communication costs
The costs associated with computation and communication should be minimum for any protocol being developed for the sensor networks. As a consequence, tracking algorithms that tend to minimize the energy consumption and adapt the existing power levels are highly desirable. Additionally, efforts should be made to turn off the nodes themselves in the absence of sensing or coordination operations. Wireless communication, specifically transmission, demands more energy compared to computational power energy. Protocol should be carefully design such that it demands less communication among nodes, and achieve same track accuracy.

2.3 Protocols for target tracking

Tracking protocols are used to detect and monitor moving objects under the area of interest. They can be based on a) strategies to receive data centrally at a sink node, which is last node interfaced to an application. b) Strategies to receive data and also to predict future state of the target. c) to track object with ease and accuracy. Major expectations, while designing a tracking protocol are 1) it should be energy efficient 2) accurate and able to track objects.

2.3.1 Target Protocol classification:

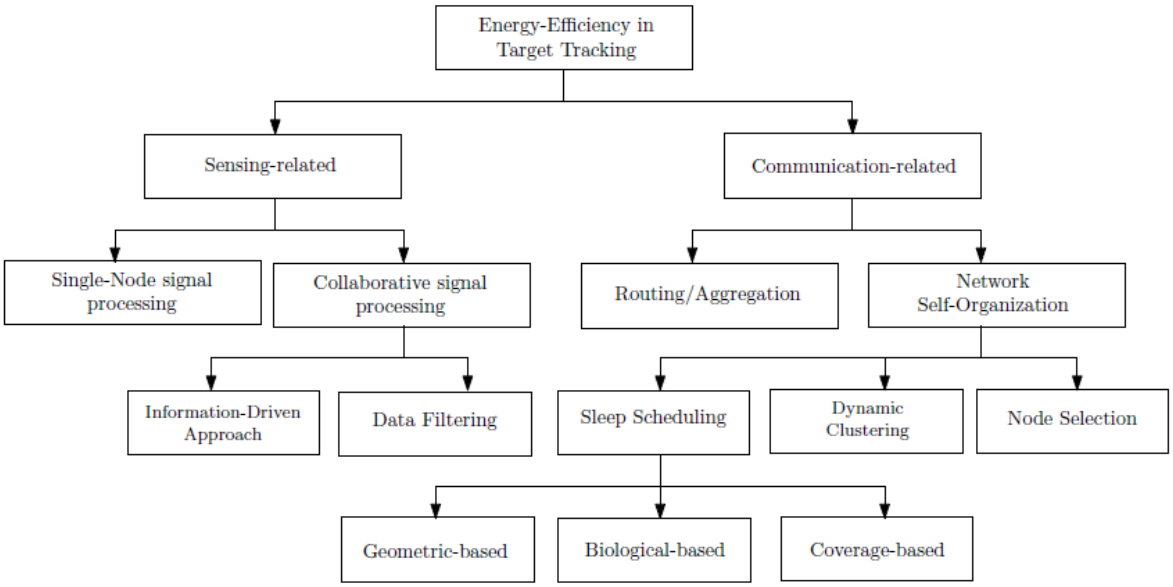

Figure:1, Classification of target tracking protocols [7]

Energy efficient protocols for target tracking are classified in two main categories; They can exploit either sensing related capabilities, or put control on communication cost among sensor nodes. Communication related protocols achieves, energy efficiency through efficient routing of information from sensor node to sink, while self organization capable sensor networks forms clusters dynamically, selecting nodes intelligently, or guiding to Medium Access Control (MAC) protocols to devise best sleep schedules to attain energy efficiency.

Protocols used for receiving data efficiently at sink node can be categorized as 1) Tree based protocols 2) Cluster based protocols. In tree-based target tracking protocols, the network is organized into a hierarchical tree. Alternatively, a sensor network may be represented as a graph, in which the sensor nodes are vertices and the edges are links among nodes that directly communicate with each other. A base station (sink node) or one of the sensor nodes that is more powerful than others act as the root of the tree and directly communicate with the user. Examples of tree-based methods include DCTC (Dynamic Convoy- Tree-based Collaboration) and STUN (or Scalable Tracking Using Networked Sensors). Cluster Based Protocols, uses an algorithm called LEACH [19] (Low-Energy Adaptive Clustering Hierarchy), to build a hierarchy tree for the network. LEACH consists of 2 phases. In the set-up phase, sensors may elect randomly among themselves a local cluster head. By doing so, the network may balance energy dissipation across the whole network. In the steady phase, sensors sense and transmit data to the base through their cluster heads. After a certain period of time spent in the steady phase, the network restarts the set-up phase again.

2.3.2 Prediction Based Protocols:

Prediction-based methods are built upon the tree- based and the cluster-based methods, with added prediction models. The models rely on heuristics based on following assumptions [4]: (a) the moving objects will stay at the current speed and direction for the next few seconds, (b) The object's speed and direction for the next few seconds can be deduced from the average of the object's movement history, (c) Different weights can be assigned to the different stages based on the history. PBS (Prediction Based Strategies) and DPR (Dual Prediction-Based Reporting) are examples of prediction-based methods.

2.3.3 Techniques of measurements:

In the target tracking, ranging information in form of distance between target and sensor node is very crucial and important. Physical distances or angles are measured to derive coordinates or localize target. Measurement task involves emitter and detector pair or only detector of acoustic or ultra sound signals. The selection of these elements has a significant impact on how well the final system will fit the application requirements. In this section, the relative merits of ranging mechanism, based on acoustic signals, are discussed.

In order to minimize cost for production of sensor nodes in large numbers, sensors' good resolution and accuracy are generally sacrificed. It means research work is required to enhance sensing accuracy for collaboration processing in target tracking.

Ranging using acoustics

Acoustic ranging is probably the most developed ranging technology in use for sensor networks. There are number of factors that make acoustics attractive. Acoustic transducers are easy to interface, and simple, inexpensive detector chipsets are available for ultrasound. However, the key advantage of using acoustics is that, timing and synchronization is easier to implement compared to RF signals.

In terms of power, acoustics performs quite well, even near the ground. Whereas RF communication suffers path loss near the ground because ground reflections are phase-shifted by 180 degrees, this is not the case for acoustic waves. Acoustic path loss near the ground under good conditions is much closer to that of outdoors.

However, acoustics has a few disadvantages as well. First, acoustic emitters tend to be physically large, especially if they emit low frequencies. Acoustics is susceptible to interference from weather conditions, such as wind that causes noise, and convective updrafts that carry signals up and away from the ground. The other main disadvantage is that acoustic signals are stopped by solid obstructions. However, for some applications this can be advantageous, such as the case of an asset tracking system which only needs to know which room the asset is in. Using acoustics a wide band of frequencies are available for use.

Some systems are based on ultrasound frequencies (typically 20 KHz to 1 MHz) while others are based on audible frequencies (100 Hz to 20 KHz). Some systems use tuned piezo emitters at specific frequencies, while others use wide-band acoustic signals. The choice of frequency depends on the application (e.g. is audible sound acceptable), as well as the environment. Experience with 40 KHz ultrasound systems outdoors indicates a typical range of about 10 meters at a voltage of 3 volts, and about 16 meters at 16 volts. The type of emitter used also has a significant effect on the performance of the system. Many ultrasound emitters are directional, substantially increasing their output in a conical beam. This can be disadvantageous from a packaging perspective, as it may require many emitters and receivers in order to support ad-hoc deployment.

Only acoustic measurements:

Audible acoustics can be very effective outdoors, because of the wide diversity of wavelengths possible. A wideband signal will be more robust to environmental interference, because of the process gain in the detection. A wide-band signal is also less susceptible to narrowband sources of noise, as well as absorption and scattering of specific frequencies. Under ideal weather conditions, audible ranging systems have been shown to achieve ranges as large as 100 m for power levels of 1/4 Watt. High power emitters such as heavy vehicles are detectable at ranges of 10's of kilometers. Acoustic range is longest at night

when the air is still and cool. The worst conditions for acoustics are warm, sunny afternoons, when heated air near the ground rises and deflects signals up and away from other ground-based receivers. Under these conditions, the same acoustic system might achieve only 10m range. Errors in line-of-sight (LoS) acoustic ranges tend in general to be independent of distance up to the limit of the signal detector. However, when obstructions or clutter are present, severe attenuation is observed, as well as radical outliers when the LoS path is completely blocked and a reflected path is detected. When designing target detecting algorithms around an acoustic ranging system it is important to take these issues into account.

Bearing estimates:

Bearing estimates for acoustic signals can often be implemented without much difficulty using simple hardware and software solutions. If the baseline between sensors is known with sufficient accuracy, a bearing estimate can be derived from the time difference of arrivals. There are several examples of implemented systems that measure direction of arrival (DoA) using acoustics, the MIT software compass, and beam-forming systems.

3. Literature survey

In literature many target tracking protocols are proposed, and they can be classified as explained in earlier sections. Summary of the work found to be relevant and worth mentioning at this stage is presented, and discussed.

Two surveys were found to be very interesting, one on energy efficient target tracking schemes and other on power control issues in wireless sensor network for all application without keeping in mind tracking. Survey carried out by Oualid Demigha, et. al. in 2012, [7] provides state of- the-art in energy-efficient target tracking schemes. Classification is carried out based on the interaction between the communication subsystem and the sensing subsystem on a single sensor node. They concluded that energy-efficiency in a collaborative WSN-based target tracking scheme can be achieved via two classes of methods: 1) sensing-related methods and 2) communication-related methods. They also had special classification for protocols that put specific assumptions on the target nature and use a “non-standard” hardware to do sensing.

In 2007, Nikolaou A. Pantazis et.el., presented survey [8] on power control issues specifically for wireless sensor network. They classified in terms of active and passive set of methods. Passive covers physical layer, fine grain, back bone based and distributed types while network, MAC and transport layer techniques are classified as active. Physical layer control is achieved mainly due to efficient on-off scheduling of sensor network components. Fine grain optimizes on-off schedule in consultation with the help of schedule of MAC layer. Coarse grain is like back bone based and distributed approach, achieves power efficiency via interacting with high level protocol. Active class of techniques, at different layer optimizes functioning of communication and functionalities.

In 2009, Hao Zhu, et. al., [3] proposed novel way to reduce dimensionality of data to be transmitted. Dimensionality reduction is well motivated because the sampling rate at a sensor may be different from the data rate supported by the sensor-to-fusion center (FC) or the inter-sensor communication links. They proposed power-efficient and channel-aware Kalman filtering (KF) based tracking method for non sparse signals based on analog-amplitude, reduced dimensionality, multi-sensor data in both the FC-based and ad hoc WSNs. They have also proposed a mean square error (MSE) based optimal channel-aware linear dimensionality reducing algorithm for a single-sensor setup.

Sampling period is important attribute while sensing. It is good to employ adaptive sampling rate to achieve same accuracy but at reduced energy consumption. Jianyong Lin, [4] and others in 2009 have proposed an adaptive energy-efficient multisensory scheduling scheme for collaborative target tracking in

WSNs. It calculates the optimal sampling interval to satisfy tracking accuracy and selects the cluster of tasking sensors according to their joint detection probability. Adaptive scheduling improves energy efficiency, keeping similar accuracy as uniform scheduling.

In 2012, Xingbo Wang, et.al., [5] suggested that although, extended Kalman filtering is a commonly used method to deal with the nonlinearity but, this offers often unsatisfactory or even unstable tracking performances. They presented a new target tracking approach which avoids the instability problem and offers superior tracking performances. They used additive and multiplicative noise in distance measurements. In our technique such noise consideration is done. We have also included energy perspective, which is missing in their experimentation.

Giving weightage to highly important information is very logical, and similar idea is implemented in paper by Tolga Onel, et.al.,[6] in 2008. They proposed a novel approach to energy saving where, information-controlled transmission power (ICTP) adjustment is carried out. Nodes with more information use higher transmission power than those that are less information.

Cluster plays important role because that is a group of sensor nodes which collectively acts on job of target tracking. Many researchers have proposed schemes which play roles in organization of clusters. Xue Wang, et. al., in 2009 [9] proposed concept of maximum entropy clustering. The sensing field is divided for parallel sensor deployment optimization. For each cluster, the coverage and energy metrics are calculated by grid exclusion algorithm and Dijkstra's algorithm, respectively. Cluster head performs swarm optimization to maximize the coverage metric and minimize the energy metric. Dynamic activation is coupled with dynamic energy management mechanism. Sensor nodes, in the vicinity of the target are awakened up and given opportunity to report their data. In [10], dynamic clusters are generated as per track of the target; such clusters then collectively monitor and track the movement of the target. This involves detecting, clustering and localization of target.

Taek Lyul Song, et.al., [11] in 2011, proposed target tracking protocol, specifically for radar in clutter, whereby collective weightage is given to target detection probability and state estimates. Wei Zhao, Ying Han, etc [13] in 2009, proposed technique in which node is selected based on probability distribution function of target state and error measurement by sensor node. Claims are made that method produces better accuracy compared to the existing methods but, energy related perspective in their work is missing.

Sensing actual values and converting in to several bits sample, and then to send them to cluster head is usual practice. Many researcher used binary sensors to send just one bit information and utilized them to save energy dissipation and achieve energy efficiency in the target tracking. For example, Marcelino Lázaro, et.al.,[14] used binary heterogeneous sensor network, with a thought process that is it is good to employ more low performance sensors, compared to few high performance ones. They considered different class of sensors, in wireless sensor network, and evaluated performance. Petar M. Djuric´ et.al, [16] in 2008 used auxiliary particle filter based prediction technique for target tracking specifically using binary sensor.

What is the maximum tracking accuracy one can achieve? This fundamental question was attempted by Yaron Rachlin, et.al., [12]. They computed fundamental limit or capacity of detecting target in wireless sensor network. They established analogy between channel capacity in context of communication and sensing capacity. They compared guess of state with guess of message, sensor noise with channel noise, detection algorithm with decoder and sensor network encoder with channel encoder. Zhou Yan; et.el, [15] proposed practical system based on Zigbee, which utilize received signal strength to estimate location of target by triangulation. Different type of nodes like reference node, end devices, router and coordinators are constructed.

Few researchers has tried to incorporate out of box ideas like, Onur Ozdemir, et.al, [17] proposed particle filter, specifically looking at imperfect channel between sensor node and cluster head. Such particle filter was named "channel aware particle filter". Wendong Xiao; et.al, proposed in [18] technique to improve information quality by providing active sensor like ultrasonic trans-receiver with adaptive scheduling. Specifically it was done using few ultrasonic transmitters, and then receiving reflected energy by many sensor nodes.

Shih, E.; et.al., [19] described excellent method to derive energy model for wireless sensor network, specifically conducting experimental work on DSP hardware and measuring actual power dissipation in radio chip. Their conclusion was inefficient hardware architecture which uses larger processing power, dominates transmit receive power needed to communicate among nodes. Efficiently designed application specific integrated circuits (ASIC) based chips improves processing power making transmit and receive power more dominating. Processing power is mainly used for error correcting encoders and decoders. This paper derives energy dissipation model and specify energy mode in terms of electronic circuit dissipation and receive transmit energy dissipation per bit of transmit received data.

Heinzelman, W.R.; et.al, [20] in 2000, proposed LEACH routing protocol to reduce energy consumption introducing cluster based arrangements. It uses various steps to formulate and organize sensor nodes, electing few cluster heads from all sensor nodes based on controlled random method. Such arrangements to receive data from sensor node through cluster heads improve overall energy efficiency. N. Patwari, et.al, [21] compiled many techniques to collaboratively identify locations or coordinates of sensor nodes in sensor field. One can use any of these methods to derive coordinates of nodes. In present work analysis we have assumed them to be known. Proposed work considers target model from [23] and [24]. It also assumes that such technique should be utilized to calculate node coordinates when they are deployed randomly.

4. Contribution, of the proposed work

4.1 Problem of target tracking:

Improving accuracy of a target trajectory in distributed wireless sensor network consisting of deterministically or randomly deployed sensors.

Tracking scenario considered in the proposed work is to track a moving vehicle through a two-dimensional sensor field. It reports trajectory of target from series of measurement carried out by the sensor nodes of a wireless sensor network. A few interesting features of the problem are worth noting.

1. There is no predefined or known path.

2. No prior knowledge of possible vehicle trajectories which can be exploited.

3. The vehicle can accelerate or decelerate in between the nearest sensors. Both of these render a traditional closest-point-of-approach (CPA) based trackers difficult to apply.

4. Many sensors can potentially make simultaneous observations and flood the network with the information. This requires the network to make intelligent decisions about who should sense and who should communicate and at what time.

Following assumptions are made in this work .

- Positions of sensor nodes are known.
- Nodes can be either stationary or mobile. If they are mobile than periodically their location are known.
- An acoustic sensor node is capable of detecting distance from source (range), and the DOA of a target when the target comes into the neighborhood (i.e., within the effective range)
- A sensor (node) has limited computing capabilities to calculate the received acoustic intensity, DOA parameters and to execute any collaborative work like data aggregation.
- Sensor nodes are dense enough such that during each sampling period, there are at least three or more number of sensors in neighborhood of target found and are powered up, i.e. in active state.
- Acoustic source is treated as a point target, and the signal propagation pattern is isotropic.
- All nodes are capable of communicating wirelessly with each other in the predefined range. Necessary protocols specifically routing and MAC layer protocols are well defined and utilized for communication.
- Power dissipation while transmitting data is assumed to be related to distance, i.e. larger the distance more power is to be transmitted.
- All nodes are having equal resources except sink node.

Various parameters are considered to quantify quality and superiority of the proposed algorithm. First and foremost is the *detection quality* which covers detection resolution, sensitivity, dynamic range, misses or false alarms and response latency. Another important parameter is *track quality* which covers tracking errors, track length, robustness against sensing gaps. *Scalability* of the given algorithm is vital parameter that takes care of size of the network. Number of events and active queries should be supported by the algorithm. *Survivability* is defined in terms of robustness against node/link failures, life of network without adding new energy resources. Last but not least, *resource usage* must be minimized specifically resources like, power or bandwidth consumption for tracking and localization.

4.2 Problem formulations:

All sensors are acoustic measuring ones and they measure amplitude of sound signal. So for state vector X and $\lambda_i^{(t)}$ is the sensor characteristics ζ_i, which includes sensor position X and σ_i^2 is known additive noise variance

$$X = [x, y]$$

$$\lambda_i = [\zeta_i, \sigma_i^2]^T$$

No time dependence for X and $\lambda_i^{(t)}$.
So measurement

$$z_i = \frac{a_i}{\|X - \zeta_i\|^{\alpha/2}} + w_i$$

a_i = random variable representing amplitude of signal at target.
α = attenuation co-efficient (known)
$\|\bullet\|$ = Second norm
w_i = zero mean Gaussian random variance with variance σ_i^2.

Problem is to localize stationary signal source using set of the sensor measurements. To uniquely localize target on a two dimensional plane, one needs at least three independent distance measurements.

Alternatively one may use time difference of arrival of signals at the sensors to estimate range or the bearing direction.

- Assume α =2 in signal propagation model.
- So signal model can be given as

$$z_i = \frac{a_i}{\|X - \zeta_i\|} + w_i$$

It leads to equation $\|X\|^2 + \|\zeta_i\|^2 - 2X\zeta_i^T = \frac{a_i}{z_i}; i = 1,2,3....$ (1)

Not considering noise term.

- So we will have set of equations
- $$\|X\|^2 + \|\zeta_1\|^2 - 2X\zeta_1^T = \frac{a_i}{z_1}.$$ (2)

– Subtracting (2) from (1)

$$\|\zeta_i\|^2 - \|\zeta_1\|^2 - 2X(\zeta_i - \zeta_1)^T = a_i\left(\frac{1}{z_i} - \frac{1}{z_1}\right).$$

$$-2X(\zeta_i - \zeta_1)^T = a_i\left(\frac{1}{z_i} - \frac{1}{z_1}\right) - \left(\|\zeta_i\|^2 - \|\zeta_1\|^2\right).$$

Let $c_i = -2(\zeta_i - \zeta_1)$ and $f_i = a_i\left(\frac{1}{z_i} - \frac{1}{z_1}\right) - \left(\|\zeta_i\|^2 - \|\zeta_1\|^2\right)$.

So we can write equation as

$$c_i^T X = f_i$$

So for given *k* sensors we can obtain *k-1* linear constraints expressed in the matrix form. To uniquely determine the location of target, three equations are required, and for equations more than three we can solve it using least square method. In that case solution will be pseudo inverse of c_{k-1}

$$X = \left[(c_{k-1}^T c_{k-1})^{-1} c_{k-1}^T\right] f_{k-1}$$

All constraints will not give equal information. Geometry of sensor placement and distance of signal source to sensor node signifies contribution from each sensor.

In equation (1) , $\frac{a_i}{z_i}; i = 1,2,3...$ represents square of distance from target to i^{th} sensor node if amplitude of received signal is measured as z_i . If using any other technique, distance is measured accurately, then it can be easily replaced with measured distance d_i, and same equation can written as

$$\|X\|^2 + \|\zeta_i\|^2 - 2X\zeta_i^T = d_i^2; i = 1,2,3....$$

Accordingly equation (2) can be written as

$$\|X\|^2 + \|\zeta_1\|^2 - 2X\zeta_1^T = d_1^2.$$

$$\|\zeta_i\|^2 - \|\zeta_1\|^2 - 2X(\zeta_i - \zeta_1)^T = d_i^2 - d_1^2.$$

$$-2X(\zeta_i - \zeta_1)^T = d_i^2 - d_1^2 - \left(\|\zeta_i\|^2 - \|\zeta_1\|^2\right)$$

let $c_i = -2(\zeta_i - \zeta_1)$ $\qquad f_i = d_i^2 - d_1^2 - \left(\|\zeta_i\|^2 - \|\zeta_1\|^2\right)$

$$c_i^T X = f_i$$

$$X = \left[(c_{k-1}{}^T c_{k-1})^{-1} c_{k-1}^T\right] f_{k-1}$$

In experimentation it is assumed that distance is measured by the sensors on the node. Only issue to be handled is track accuracy with noise added in the sample.

4.3 Experimental scenario:

To simulate target moving in sensor field equipped with numerous sensor nodes it is essential to create robust framework for simulation environment. Such a frame work is divided into several important functionalities, described as follows.

a) Creation of sensor field equipped with sensor nodes.

It is expected from framework to deploy number of nodes in user defined field, either in deterministically randomly. Framework creates two dimensional sensor field with uniformly distributed sensors. They are at known coordinates and have unique number attached with them. Coordinate of such nodes will be made available to simulation environment. Coordinates of sensor nodes in actual case is found out by robust node cooperative localization algorithms using distance measurements among sensor nodes. This algorithm development is beyond scope of the present work.

b) Creation of target moving in the sensor field.

Simulation framework defines target movement. It creates predefine trajectory of point target in the sensor field. User will input target velocity, initial position and number of points along target path. It is possible to define random velocity and noise can be added to create variations in the target trajectory.

c) Creating clusters from deployed nodes,

As per user specification, entire sensor field is divided into several clusters. Clusters are marked with different colors to distinguish from each other. At present in the frame work regular square area is considered for clustering.

d) Measurements by sensor nodes.

Nodes are expected to use on board sensor and measure parameter. In present case distance is measured and used for prediction of the target position with the time stamp. Simulation framework will calculate distance from each sensor node to the target position with incremental time stamp. Result of such measurement at node side is a time series of distance values corresponding to a target position. This information is exchanged among sensor nodes and delivered finally to a sink node. It is assumed that robust routing protocol is taking care of this transfer. Amount of data needed to be transferred from a particular sensor node to sink is controlled by energy saving algorithm. Lesser is such exchange, more is the conservation in energy.

In actual case, sensor nodes cannot accurately measure very large distances. So, in this framework there is a provision to define limit on the range measurement. Accordingly each sensor may not measure distances greater than set limit from the target. Sensor network then estimates target position using available limited data.

e) Estimation of target position.

This part of simulation framework is estimating target position using various algorithms. It uses data received by the sensor nodes specifically distance measured from target position to sensor node and coordinates of sensor nodes in sensor field. One such estimation is least mean square estimation(LMSE) which is done at level of cluster head.

f) Energy utilization and calculation of energy dissipated

Framework takes care of energy utilized by each node and by sensor field to give us estimate of the energy utilized by the network. It gives fair indication of how much energy is utilized by wireless sensor network collectively in tracking target with finite accuracy. Energy model [15]is utilized to implement this mechanism. It is found from model that communication is a significant cost as compared to CPU computation power. Transmission at longer distance needs more energy compared to shorter distance but not significant as per model used in literature.

g) Error calculations

One of important attribute of target tracking is its accuracy. Accuracy is defined as ability of given algorithm or system to follow actual value. In this case it is trajectory of the target in the sensor field. In this framework mean square error between estimated target and actual target position is taken as a measure of target accuracy. Cumulative RMS error is considered as performance metric for target accuracy.

4.4 Experimental results:

Using LSE triangulation target tracking accuracy is examined. Track is generated by standard state model. Tracking error is derived in terms of MSE in meters against time index of target. MSE graph explains magnitude of error and performance of the algorithm for a given set of attributes. Several experimental conditions have been simulated. First case explains tracking error behavior within cluster if sufficient numbers of sensor nodes are not available. Case 2 shows that tracking error can be minimized by increasing node density. Case 3-4-5 cumulatively indicates relationship between tracking and distance measurement error. They shows results considering incremental errors in the distance measurement by the sensor nodes. Results are plotted to show relationship between MSE of the tracking error and distance measurement error. This relation is found to be non linear. In case 6, effect of cluster size is examined. Simulation is carried out for different cluster size and corresponding tracking RMSE is calculated. Plot shows that relation between them is non linear with negative slope.

Case: 1

Simulation scenario has following parameters:

- Sensor field 100m x 100m area,
- 200 nodes,
- cluster size 25m x 25m,

- distance measurement range 15m,
- zero measurement error of sensor node.

Error is taken as sample of zero mean, unity variance normally distributed random process. If measurement error is taken as 1, then sample from zero mean normal distribution is multiplied by 1 and added in distance measurements as error. If the value is zero, then there is no error in the measurement. So maximum error will be added in few cases where outcome of the process is very large. Blue circles hows, original target positions and red small circle shows its estimation algorithm LMSE.

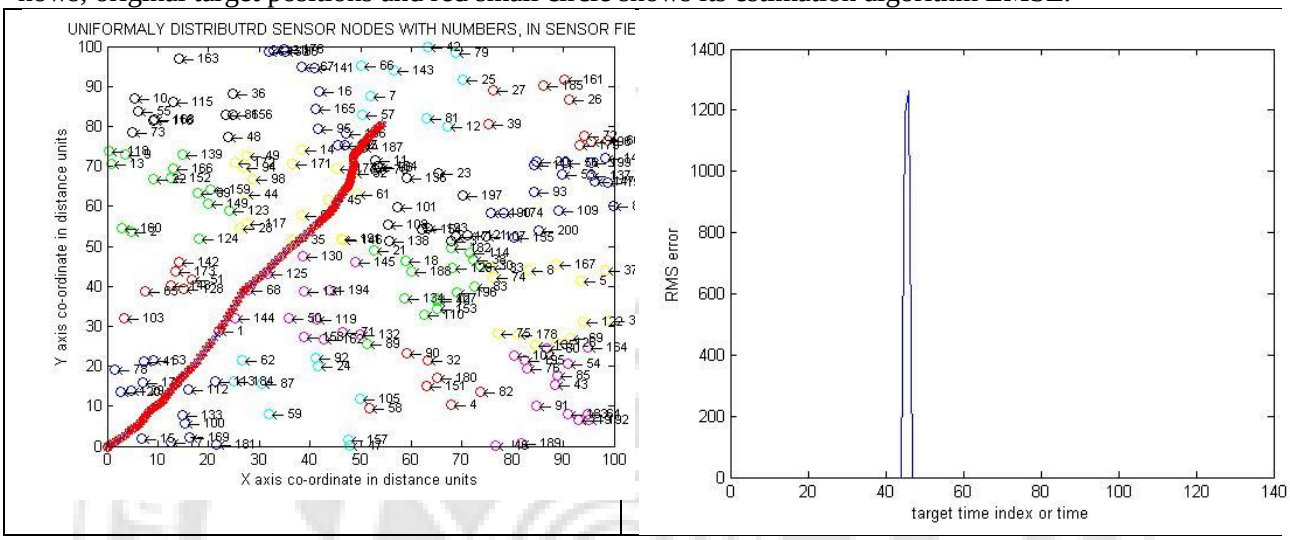
UNIFORMALY DISTRIBUTRD SENSOR NODES WITH NUMBERS, IN SENSOR FIE
Y axis co-ordinate in distance units
X axis co-ordinate in distance units
RMS error
target time index or time

Figure:2 Abrupt error around time index 45, Case of 300 nodes deployed in 100m x100m with no error in distance measurement.

In Figure 2 abrupt error can be noticed due to insufficient number of nodes for valid measurement. For time instance around 45, RMSE shoots up due to geometry of target movement as sufficient numbers of sensor nodes are not available to estimate target at that target position. Considering the case when this problem is solved is by enhancing number of nodes to 300, and it can also be done by considering layout of the sensor nodes.

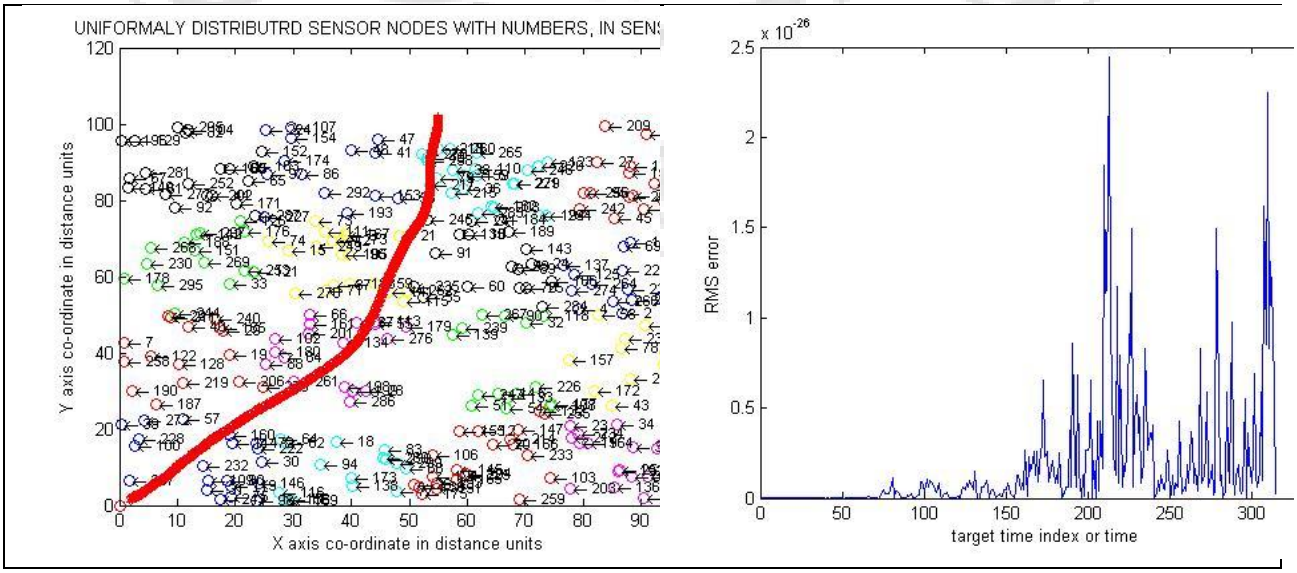
UNIFORMALY DISTRIBUTRD SENSOR NODES WITH NUMBERS, IN SENS
Y axis co-ordinate in distance units
X axis co-ordinate in distance units
x 10^-26
RMS error
target time index or time

Figure 3 Case of 300 nodes deployed in 100m x100m with no error in distance measurement.

Note that RMS error is of order 10^{-26} or less for all instances of targets, which is negligible. So when there is no error in distance measurements estimation of target is almost perfect.

Case: 3

Following results are for 300 nodes, and distance measurement error of 0.05, keeping all other parameters fixed as case 1 and 2.

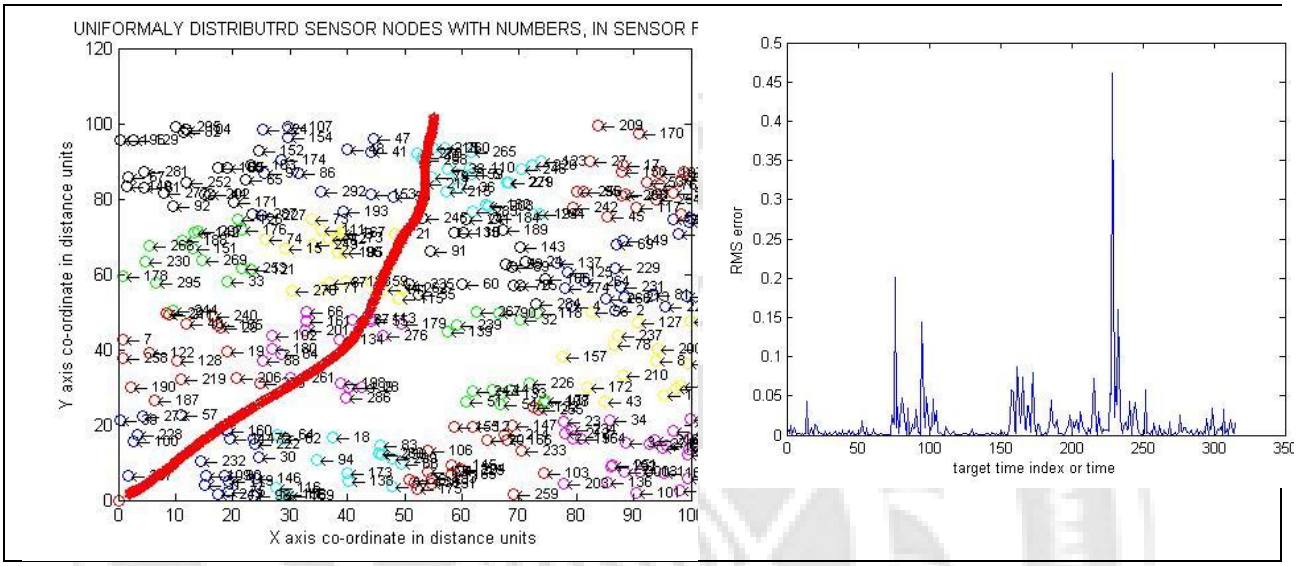
UNIFORMALY DISTRIBUTRD SENSOR NODES WITH NUMBERS, IN SENSOR F
Y axis co-ordinate in distance units
X axis co-ordinate in distance units
RMS error
target time index or time

Figure:4 Case of 300 nodes deployed in 100mx100m with 0.05 distance measurement error variance. It can be seen that MSE tracking error in this case is of order 10^{-1} or less, but it is higher than that of earlier case.

Case : 4

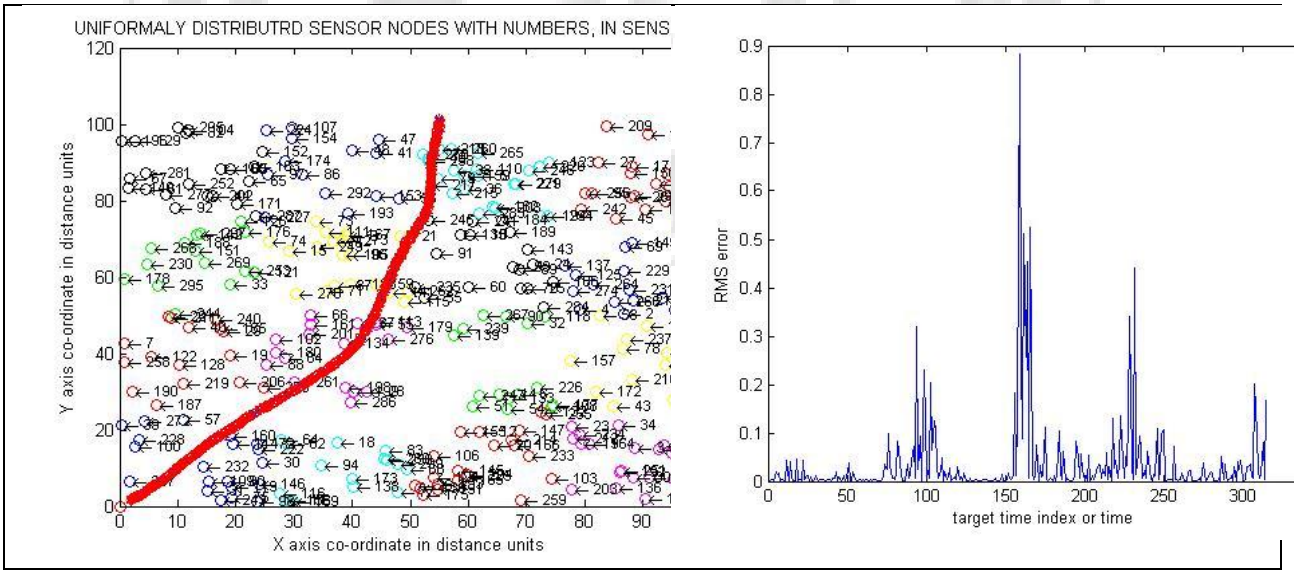
UNIFORMALY DISTRIBUTRD SENSOR NODES WITH NUMBERS, IN SENS
Y axis co-ordinate in distance units
X axis co-ordinate in distance units
RMS error
target time index or time

Figure:5 Case of 300 nodes deployed in 100mx100m with 0.075 distance measurement error variance. It can be seen that order of tracking MSE is 0.1 to 0.9 and RMSE = 0.0341, for 0.075 meter error variance in measurement.

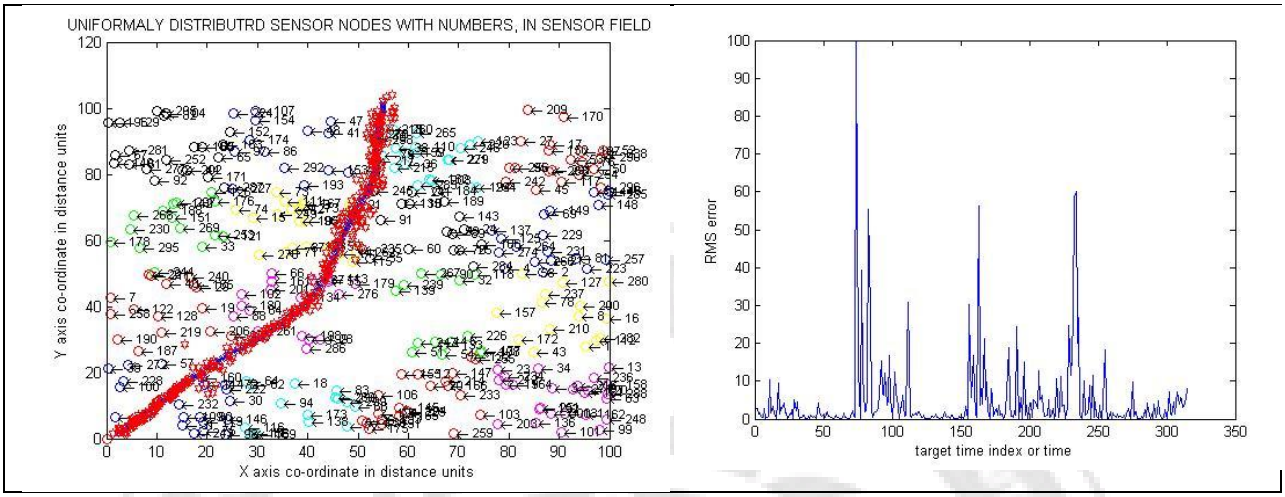
UNIFORMALY DISTRIBUTRD SENSOR NODES WITH NUMBERS, IN SENSOR FIELD
Y axis co-ordinate in distance units
X axis co-ordinate in distance units
RMS error
target time index or time

Figure:6 Case of 300 nodes deployed in 100mx100m with 0.9 distance measurement error variance.

Case :5

Finally it was interesting to find that as distance measurement error increases how RMSE of the tracking behaves. This result is tabulated in table1, where different values of distance measurement error are considered, and corresponding RMSE is calculated and tabulated.

Table1

Sr no	Error in measurement of distance, (Em) Actual distance±(randn()*Em) meters	RMSE in target localization, meters
1	0.05	0.0137
2	0.075	0.0341
3	0.1	0.0674
4	0.2	0.2242
5	0.3	0.4899
6	0.4	1.0914
7	0.5	1.2843
8	0.6	2.1535
9	0.7	2.4857
10	0.9	4.5850
11	1	7.7062

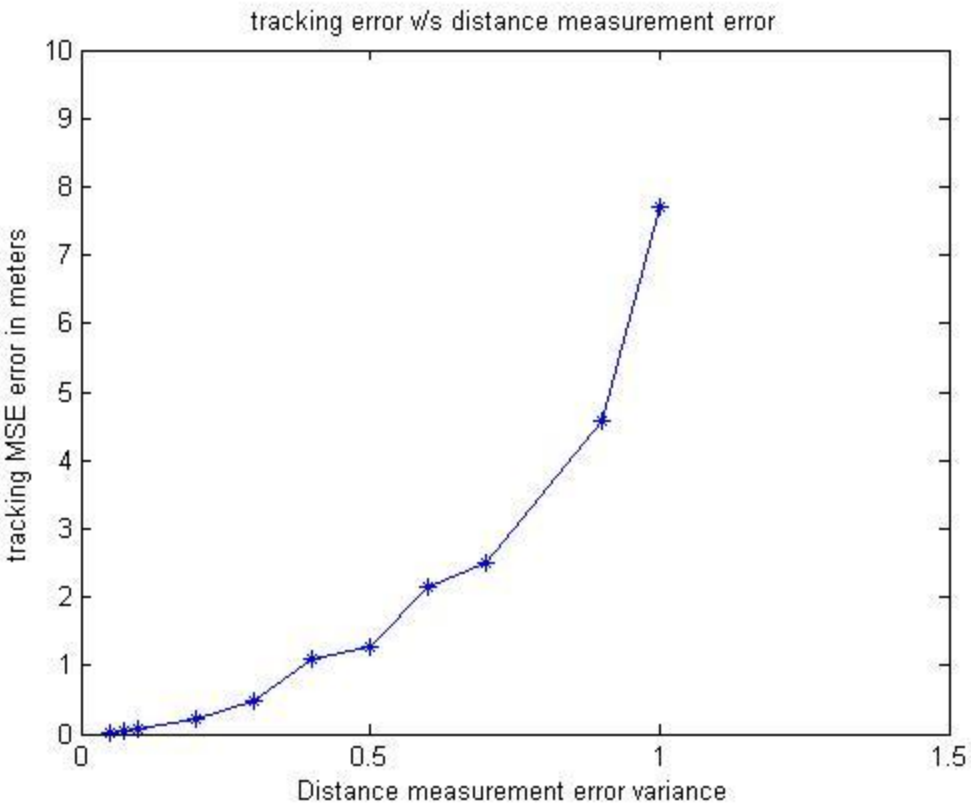

Figure :7 Tracking MSE error v/s Distance measurement error

Similarly data is derived for energy consumed for various node densities.

Case :6

For different cluster size with same specification experiment is repeated, and each time target accuracy is measured. Larger is size of cluster lesser will be RMSE error. Distance error measurement is considered with 0.5. Here meaning of distance error measurement as follows; for error in distance measurement i.e. Em=0.5, means actual distance ±(randn()*Em) meters. In this case sensor field is considered having 300 deployed nodes and distributed in 100 x 100 area. Cluster size is kept variable 20, 25 and 50. Distance measurement range of each sensor node is considered 15m.

Table 2

Sr no	Cluster size	RMSE in target localization, meters
1	20	10.483
2	25	1.2843
3	50	0.7423

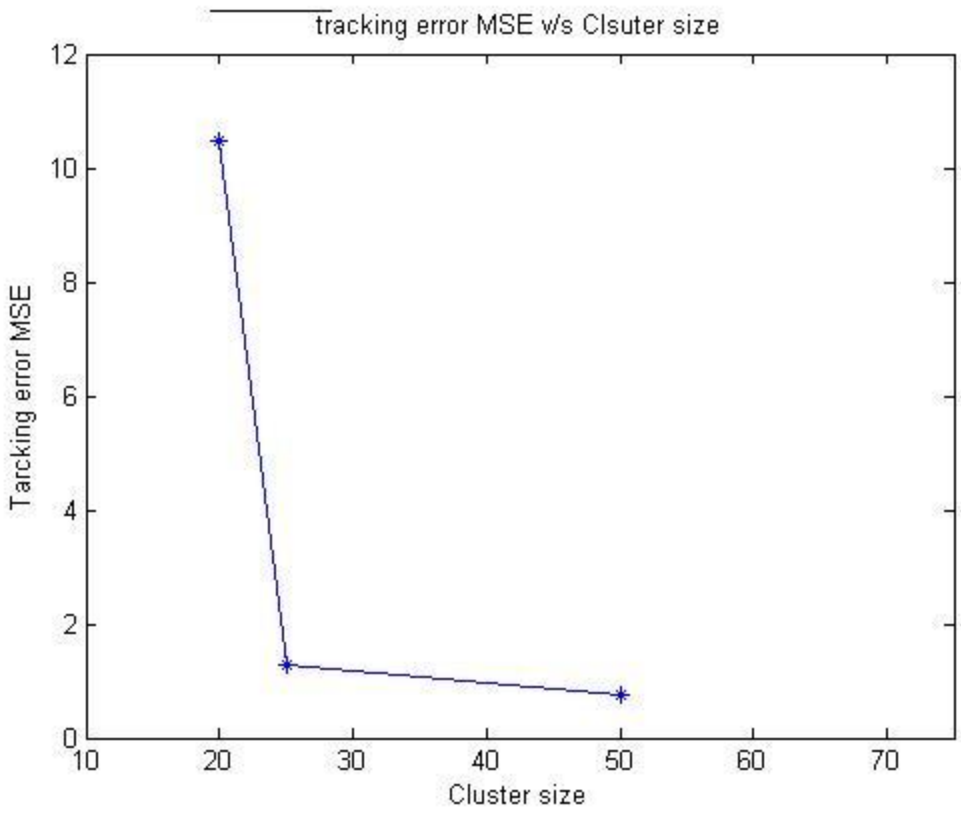

Figure:8 Tracking MSE error v/s cluster size

Similarly effects of, measurement range on accuracy of target tracking is calculated . Also experiments are carried out for estimating target using less number of node readings compared to nodes that have opportunity to measure distance. Such efforts improve energy efficiency. Efforts are made to implement Kalman filter and Extended kalman filter for as an estimation protocols which improves target tracking accuracy based on data received from each sensor nodes.

4.5 Thesis outline:

Research carried out, is organized as follows:
Chapter1: Introduction to wireless sensor network, its significance, constraints of wireless sensor network and it's common applications.
Chapter 2: Target tracking application of WSN, challenges, measurement metrics for performance, basic classification of target tracking techniques.
Chapter 3: Problem formulation of target tracking.
Chapter 4: Literature survey on target tracking protocols, and energy efficient techniques.
Chapter 5: Simulation environment and frame work.
Chapter 6: Simulation scenarios and experiment descriptions.
Chapter 7: Results
Chapter 8: Conclusions and Future work.

5. Conclusion:

Thesis examines impact of distance measurement error on target track accuracy; also looks at effect of

variations in size of clusters, range of measurement, and node density. Another important parameter it addresses is resource utilization of the wireless sensor network. It examines energy utilization when finite number of nodes only contribute instead of all. Such efforts save energy utilized for target tracking. Accuracy for tracking can be improved by various estimation algorithms like EKF particle filter but does not contribute in energy saving for target tracking. The work develops simulation framework which can be utilized to conduct number of experiments using different target tracking protocols.

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